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ENERGY EFFICIENT DISTILLATION COLUMNS ANALYSIS FOR AN AROMATIC SEPARATION PROCESS

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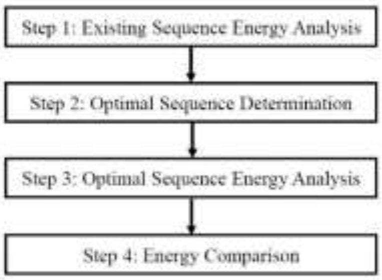
Graphical abstract



Abstract

Energy savings is a major challenge in distillation operations. However, there is still one problem, which is how do we improve the energy efficiency of the existing distillation column systems without major modifications. Recently, a new energy efficient distillation columns methodology that will be able to improve energy efficiency of the existing separation systems without having major modifications has been developed. Therefore, the objective of this paper is to present a new improvement of the existing methodology by designing an optimal sequence of energy efficient distillation columns using a driving force method. Accordingly, the methodology is divided into four hierarchical sequential stages: i) existing sequence energy analysis, ii) optimal sequence determination, iii) optimal sequence energy analysis, and iv) energy comparison and economic analysis. The capability of this methodology is tested in designing an optimal synthesis of energy efficient distillation columns sequence of an aromatics separation unit. The existing aromatics separation unit consists of six compounds (Methylcyclopentane (MCP), Benzene, Methylcyclohexane (MCH), Toluene, m-Xylene and o-Xylene) with five direct sequence distillation columns being simulated using a simple and reliable short-cut method and rigorously tested within an Aspen HYSYS® simulation environment. The energy and economic analyses show that the optimal sequence determined by the driving force method has a better energy reduction with a total of 6.78% energy savings and a return of investment of 3.10 with a payback period of 4 months. It can be concluded that, the sequence determined by the driving force method is not only capable in reducing energy consumption, but also has a better economic cost for an aromatic separation unit.

Keywords: Energy; energy efficient distillation columns; aromatic separation process; simulation

Abstrak

Penjimatan tenaga adalah satu cabaran dalam operasi penyulingan. Walau bagaimanapun, masih ada satu masalah, iaitu bagaimana kita meningkatkan kecekapan tenaga daripada sistem ruangan penyulingan sedia ada tanpa pengubahsuaian utama. Baru-baru ini, sebuah metodologi baru untuk ruangan penyulingan cekap tenaga yang berkesan akan dapat meningkatkan kecekapan tenaga daripada sistem pemisahan sedia ada tanpa perlu pengubahsuaian utama telah dibangunkan. Oleh itu, objektif kajian ini adalah untuk membentangkan peningkatan baru untuk metodologi yang sedia ada dengan mereka bentuk satu urutan optimum bagi ruangan penulenan dengan menggunakan kaedah daya penggerak. Oleh itu, kaedah ini dibahagikan kepada empat peringkat hierarki berurutan: i) analisis urutan tenaga yang sedia ada, ii) penentuan urutan yang optimum, iii) analisis urutan tenaga yang optimum, dan iv) perbandingan tenaga dan analisis ekonomi. Keupayaan metodologi ini diuji dalam mereka bentuk sintesis yang optimum bagi ruangan penyulingan cekap tenaga untuk urutan unit pemisahan aromatik. Unit pemisahan aromatik yang sedia ada terdiri daripada enam sebatian (Methylcyclopentane (PKM), Benzene, Methylcyclohexane (MCH), Toluene, m-Xylene dan o-Xylene) dengan lima urutan langsung untuk ruangan penyulingan, disimulasi menggunakan kaedah pintas mudah dan boleh dipercayai dalam persekitaran simulasi Aspen HYSYS®. Analisis tenaga dan ekonomi dilakukan menunjukkan bahawa urutan optimum ditentukan dengan kaedah daya penggerak mempunyai pengurangan tenaga yang lebih baik iaitu sebanyak 6.78% penjimatan tenaga dan pulangan pelaburan sebanyak 3.10 dengan masa pelunasan 4 bulan. Ia boleh disimpulkan bahawa, urutan yang ditentukan oleh kaedah daya penggerak bukan sahaja mampu mengurangkan penggunaan tenaga, tetapi juga mempunyai kos ekonomi yang lebih baik untuk unit pemisahan aromatik.

Kata kunci: Tenaga; ruangan penyulingan cekap tenaga; unit pemisahan aromatik; simulasi

1.0 INTRODUCTION

Distillation process is one of the most important unit operations for the separation methods in the chemical process industry. Most of chemical mixtures require this typical separation process in order to produce individual pure product. This separation process has well-known contributions and benefits, as well as a huge impact on operating expenditure and investment costs in chemical plants. [1-2]

There is a significant rise of interest in determining energy efficient distillation columns designs and multiple column configurations. Designs are usually based on minimizing capital investment costs because energy was cheap in the past. Nowadays, the price of energy has varied dramatically over the last few years due to increasing operating cost as well as fluctuating world oil prices. However, there is no denying the fact that energy considerations will have a more significant impact on distillation design and retrofitting in the future. [3]

The determination of feasible sequences of multiple distillation columns, whether on the basis of minimum overall energy consumption, total annualized costs, sustainability, or some other metric, has been the subject of academic and industrial investigation for many years. The synthesis of distillation columns sequence for multicomponent feed mixtures has been a challenging problem in process design for several decades. A large number of researches have been conducted to highlight the advantages of a variety of methodologies for determining the best sequence for a given number of component feed mixture. These include early methodologies such as the use of heuristics, genetic algorithms and mixed integer nonlinear programming (MINLP) methods [4].

Significant savings in the utilities for aromatics separation process can be achieved by using a driving force method in innovative configurations. However, the conventional distillation columns may be used in aromatics separation design, and only the configurations/sequences need to be changed. Since multiple products are produced by the aromatics separation process and due to the large amount of energy required, aromatics separation process provides several opportunities for economical process improvement. This can be systematically and effectively achieved by using a driving force method.

For distillation column, the driving force can be defined as the difference in composition of a component *i* between the vapour and liquid phase due to the difference of properties such as boiling point and vapour pressure of component *i* and the others. The driving force can be measured by the binary pair of key multi-component mixture or binary mixture. Theoretically, when the driving force approaches zero, the separation of the key component binary mixture becomes more difficult and when the driving force approaches the maximum value, the separation between the two components becomes easier [5].

2.0 SUSTAINABLE ENERGY EFFICIENT DISTILLATION COLUMNS SEQUENCE METHODOLOGY

To perform the study and analysis of the sustainability and energy saving improvement for the energy efficient aromatics separation sequence (EEDCs), EEDCs sequence methodology is developed based on the driving force method. Accordingly, the methodology consists of four hierarchical steps as shown in figure 1.

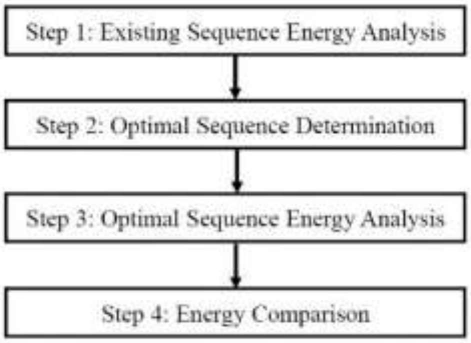


Figure 1 Energy Efficient Distillation Columns Sequence (EEDCs) Methodology

In the first step, a simple and reliable short-cut method of process simulator (Aspen HYSYS) is used to simulate a base (existing) columns sequence. The energy used to recover individual fractions in the base sequence is analysed and taken as a reference. In the second stage, an optimal columns sequence is determined by using a driving force method. All individual driving force curves for all adjacent components are plotted and the optimal sequence is determined based on the plotted driving force curves. Details of the step-by-step algorithm in plotting the driving force can be obtained elsewhere [4].

The highest value of maximum driving force which corresponds to the splitting of the adjacent component will be separated first, while the lowest value of the maximum driving force will be separated last. According to the driving force method, at the highest value of the maximum driving force, the separation becomes easy and the energy required to maintain the separation is at the minimum. Whereas, at the lowest value of the maximum driving force, the separation becomes difficult and the energy required to make the separation feasible is at the maximum [5]. The optimal sequence is then simulated in step three using a simple and reliable short-cut method (using Aspen HYSYS), where the energy used in the optimal sequence is analysed.

Finally, the energy used in the optimal sequence is compared with the base sequence. The total energy from existing aromatic separation sequence and optimal aromatic separation sequence by using driving force is compared. Then, the percentage difference of energy is calculated. After that, the economic analysis is done in terms of rate of return of investment (ROI). In order to analyze the economic performance, the operating cost and modification cost must be calculated. The capability of this methodology is tested in designing a minimum energy distillation column sequence for aromatics separation process, which consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, o-xylene, m-xylene) with five direct sequence distillation columns.

3.0 RESULTS AND DISCUSSION

The capability of the proposed methodology is tested in designing sustainable energy distillation column sequence for aromatics separation process. The objective of the aromatics separation process is to recover individual fractions using a distillation column.

3.1 Existing Sequence Energy

The existing aromatics separation process consists of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, o-xylene, m-xylene) with five direct sequence distillation columns. Figure 2 illustrates the existing separation sequence (direct sequence) of the aromatics separation process. The feed composition, temperature and pressure are described in Table 1.

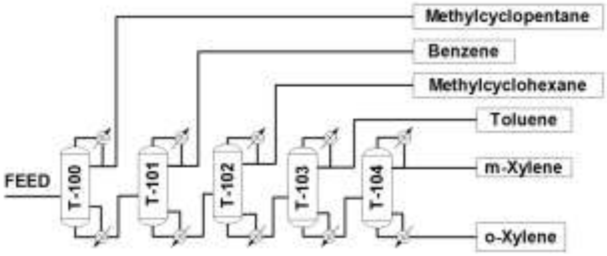


Figure 2 Existing Separation Sequence (Direct Sequence) of Aromatics Separation Process

The existing aromatics mixtures separation process was simulated using a simple and reliable short-method using Aspen HYSS environment. From the results, a total of 20.073 MW energy was used to recover 99.99 % of the product.

3.2 Optimal Sequence Determination

The optimal sequence of aromatic mixtures was determined by using a driving force method. The driving force curve was generated by using two binary components to calculate the value of α. All individual curves are plotted and shown in figure 3, and the optimal sequence was determined based on the plotted driving force curve.

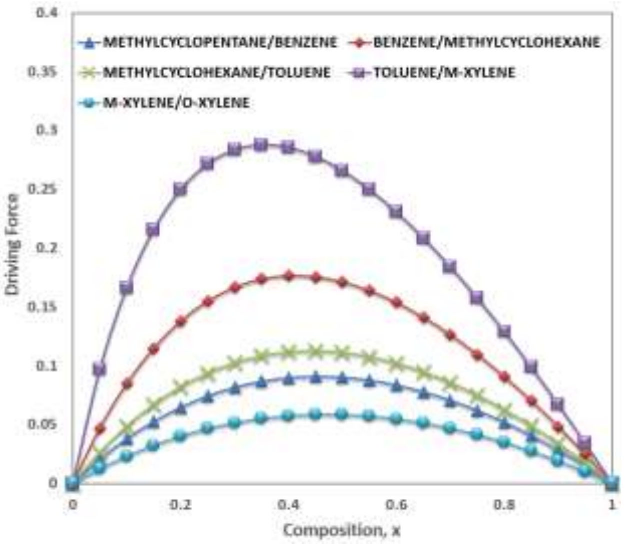


Figure 3 Driving Force Curve for set of binary component at uniform pressure

3.3 Optimal Sequence Energy Analysis

Based on driving force method curve graph result, a new optimal sequence determined by driving force method was simulated using a short-cut method within Aspen HYSYS environment where a total of 18.71 MW of energy was used for the same product recovery. Figure 4 illustrates the optimal sequence using a Driving Force method.

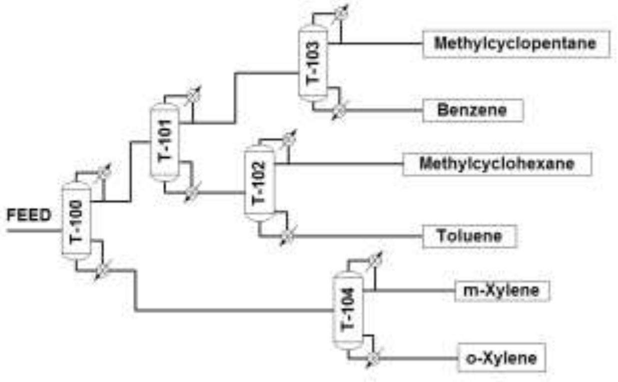


Figure 4 Simplified flow sheet illustrating the optimal Driving Force sequence of aromatics separation process

3.4 Energy Comparison And Economic Analysis

Total energy used to recover every single fraction for the existing direct sequence and the new optimal sequence determined by the driving force method are shown in Table 2. The results show that the maximum of 6.78% energy reduction was achieved by changing the sequence suggested by the driving force method. It can be concluded that, the sequence determined by the driving force method is able to reduce the energy used for aromatics separation process.

Table 2 Comparison in duty required between direct sequence and driving force sequence

Distillation Column Unit	Direct Sequence	Driving Force Sequence	Percentage Difference (%)
Total Condenser Duty (MW)	9.7806	9.1001	6.96
Total Reboiler Duty (MW)	10.2924	9.6120	6.61
TOTAL	20.0730	18.7121	**6.78**

The economic analysis is carried out by considering the cost of modifying the direct sequence distillation unit arrangement into that of the driving force, the cost of repiping works as the capital cost and the reduction in condenser and reboiler duty as the net earnings. In order to evaluate the economic analysis, the length of pipes needed for repiping works is estimated by comparing the drawing of the original sequence as well as drawing of the direct sequence with the modified one that is illustrates in figure 5.

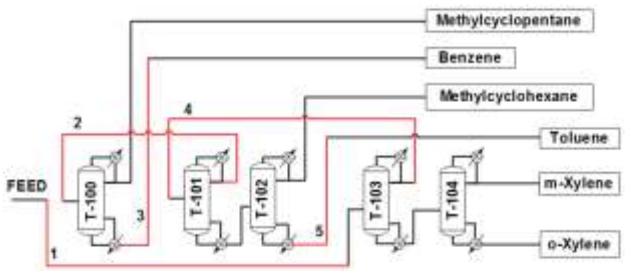


Figure 5 Repiping modification to from direct sequence into driving force

Based on the calculation regarding the economic analysis, the return of investment (ROI) generated is 3.10. The payback period for the modification of the process from direct method into the driving force method is about 0.32 year or approximately 4 months. Table 3 summarizes all the economic analysis of the modification process of the aromatic separation plant.

Table 3 Return of Investment (ROI) and Payback Period

Repiping Cost (US$/yr)	159,973
Reboiler Saving (US$/yr)	247,632
Condenser Saving (US$/yr)	247,631
ROI	3.10
Payback Period (yr)	0.32

4.0 CONCLUSION

The study and analysis of the energy saving improvement for the aromatics separation process by using a driving force method has been successfully performed. The existing aromatics separation process consisting of six compounds (methylcyclopentane (MCP), benzene, methylcyclohexane (MCH), toluene, o-xylene, m-xylene) with five direct sequence distillation columns was simulated using a simple and reliable short-cut method within an Aspen HYSYS environment. A total of 20.1 MW of energy was used to achieve 99.9% of product recovery. A new optimal sequence determined by the driving force method was simulated using a short-cut method within an Aspen HYSYS environment where a total of 18.7 MW of energy was used for the same product recovery. The results show that the maximum of 7.0% energy reduction was achieved by changing the sequence suggested by the driving force method. The economic analysis on the viability of modification from direct sequence to driving force sequence, considering the cost of repiping and the savings form the reduction in energy requirement resulted in ROI of 3.10 and payback period of approximately 4 months. It can be concluded that, the sequence determined by the driving force method is able to reduce energy used for aromatics separation process in an easy, practical and systematic manner.

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